Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings

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LONG-TERM GOALS

Our long-term scientific goals are to understand the upper ocean dynamics, to understand the coupling between ocean and atmosphere via air–sea fluxes, and to quantify the mechanisms of air–sea interactions. Our ultimate goal is to help develop improved parameterizations of air–sea fluxes in ocean–atmosphere models and parameterization of small-scale processes in the upper ocean and in the stratified interior.

OBJECTIVES

The energy of tropical cyclones is derived from the ocean via the air–sea flux. The oceanic heat content in the mixed layer and the air–sea enthalpy flux play important roles in determining the typhoon's maximum potential intensity, structure, energy, trajectory, and dynamic evolution. Forced by tropical cyclones, the most energetic oceanic processes are surface waves, wind-driven current, shear and turbulence, and inertial currents. To understand the dynamics and structures of tropical cyclones, one needs to understand these oceanic processes and quantify their effects on the air–sea flux during the passage of cyclones. Small-scale and meso-scale oceanic processes in the wake region also play crucial roles in determining the recovery of oceanic conditions after their responses to tropical cyclones. In tropical cyclones, these processes are the least understood primarily because of the paucity of direct field observations, consequently leading to large uncertainties in air–sea flux parameterizations.

For this project, we design an experiment to provide in-situ oceanic observations in the western Pacific on the paths of tropical cyclones to understand the coupled dynamics in a wide range of oceanic and

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atmospheric conditions. Our broad focus is on surface waves, inertial waves, shear instability, internal waves, and meso-scale eddies before, during, and after the tropical cyclones. Primary objectives of this project are (1) to provide observations of oceanic responses to a wide range of atmospheric wind forcing including tropical cyclones, (2) to provide observations of effects of oceanic conditions on the strength of tropical cyclones, and (3) to help provide better parameterization schemes for air–sea fluxes, especially in the tropical cyclone extreme wind forcing regime, and for interior mixing.

APPROACH

We are making long-term mooring observations of atmosphere forcing and upper oceanic conditions in the western Pacific on the likely paths of tropical cyclones in 2009 and 2010. During the 2010 typhoon season, we will air-launch EM-APEX floats in front of typhoons. EM-APEX floats will transmit near-real time observations of velocity, temperature, salinity, and GPS position via Iridium satellite.

During the 2010 typhoon season (intensive observation period of ITOP), subsurface temperature measurements on the moorings will be transmitted via Iridium satellite and one upward-looking 75-kHz Long Ranger ADCP will be equipped on each of three moorings. All moorings will be recovered in October–November 2010.

WORK COMPLETED

Three ATLAS surface-buoy moorings were deployed in the western Pacific Ocean in March 2009. The configuration of moorings is shown in Fig. 1. Each mooring is equipped with a series of more than 10 temperature sensors in the upper 500 m. They are recovered and redeployed in September–October 2009. The operation route and mooring positions are shown in Fig. 2. These moorings will be maintained until the end of 2010 typhoon season. Each buoy is equipped with a suit of meteorological sensors. Measurements of air pressure, air temperature, sea surface temperature, wind speed and direction, humidity, solar radiation, and buoy positions are transmitted via Iridium satellite every 6 hrs and are published in http://140.112.68.246/~itop and http://kirin.apl.washington.edu/~itop. Positions and water depths of three moorings are listed in Table 1.

Table 1. ITOP ATLAS mooring location and depth

Site	Lat	Lon	Nominal Depth
A1	20°20.84'N	127°50.17'E	5570m
A2	20°36.37'N	123°49.93'E	5610m
A3	18°54.14'N	126°03.02'E	5680m

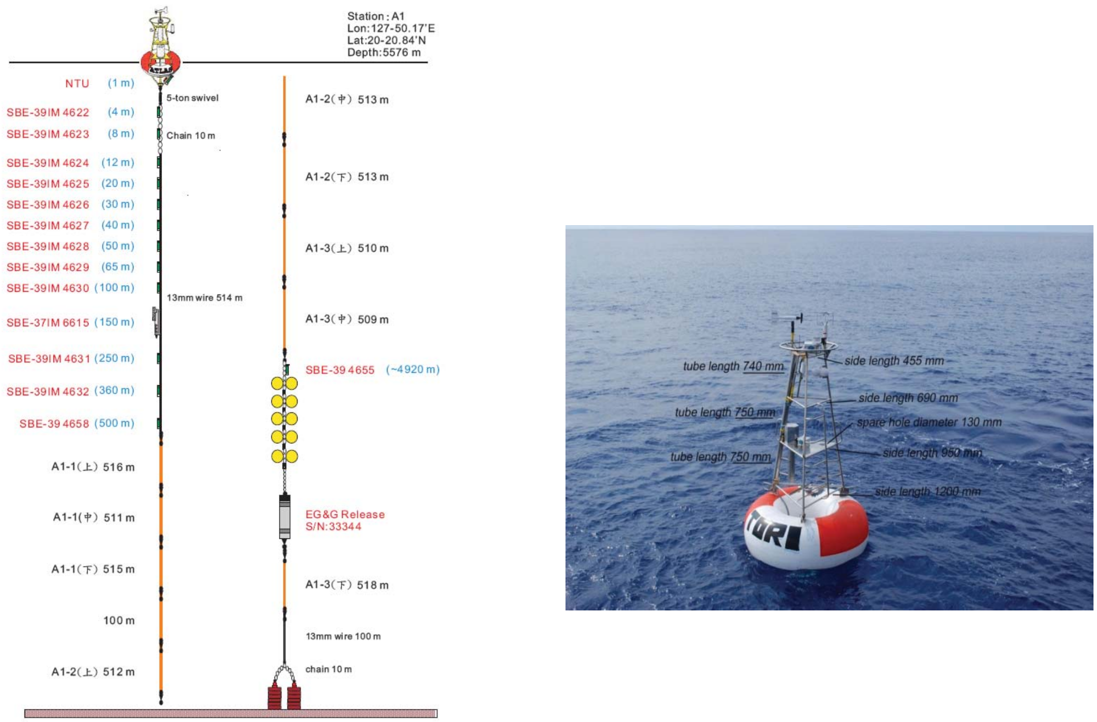

Figure 1. Schematic diagram of mooring A1 and photo of ITOP buoy. Moorings A2 and A3 are similar to that of A1.

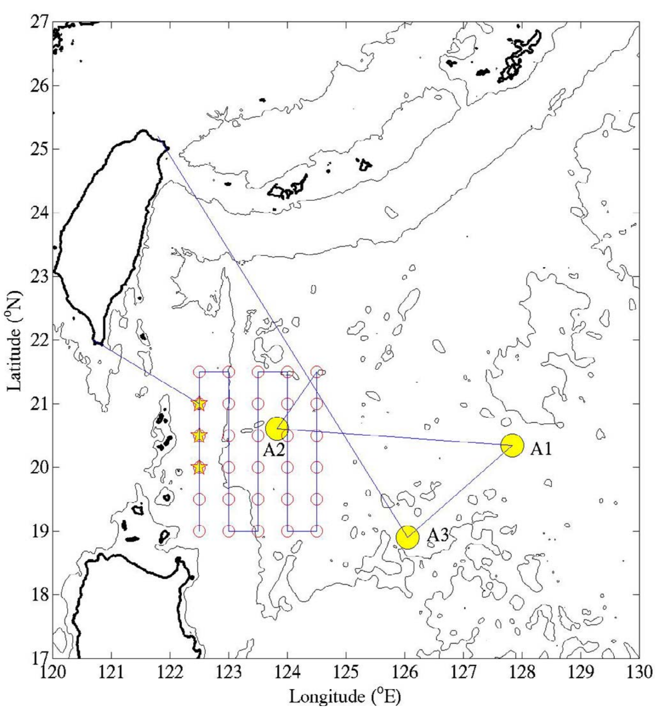

Figure 2. The cruise operation route for Sept. 19–Oct. 9, 2009 to service three ATLAS surface-buoy moorings A1, A2, and A3 (yellow dots), CTD stations (red circles), and time series stations (stars).

RESULTS

Several typhoons passed A1, A2, and A3 moorings in 2009. Meteorology observations showed air pressure dropped below 990 hPa when typhoons passed (Figs. 3-5). Maximum wind speed reached ~30 m s^{-1}. Typhoon Morakot passed moorings A1, A2, and A3 in August and landed on Taiwan causing major damage.

Temperature observations in the upper 500 m showed strong variations at a time scale of ~10s days superimposed with rapid cooling events, e.g., May 2–4 at A1, May 28–Jun 1 at A2, and Jun 15–20 at A3. After typhoon Morakot, temperature in the upper 50 m at the moorings dropped by ~ 1^{o}C. Further analysis of mooring data will be performed.

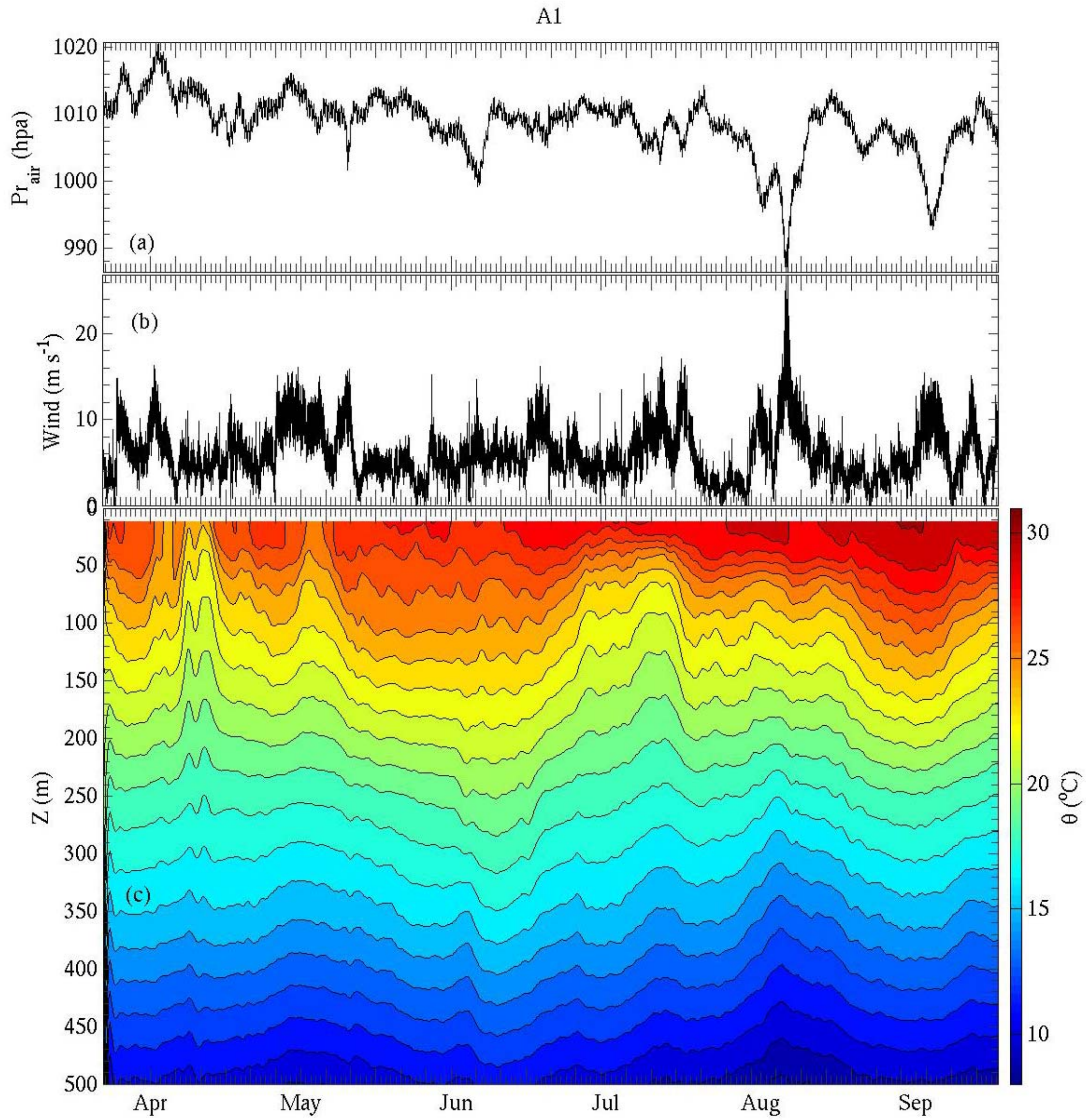

Figure 3. Air pressure, wind speed, and temperature observations at A1 mooring.

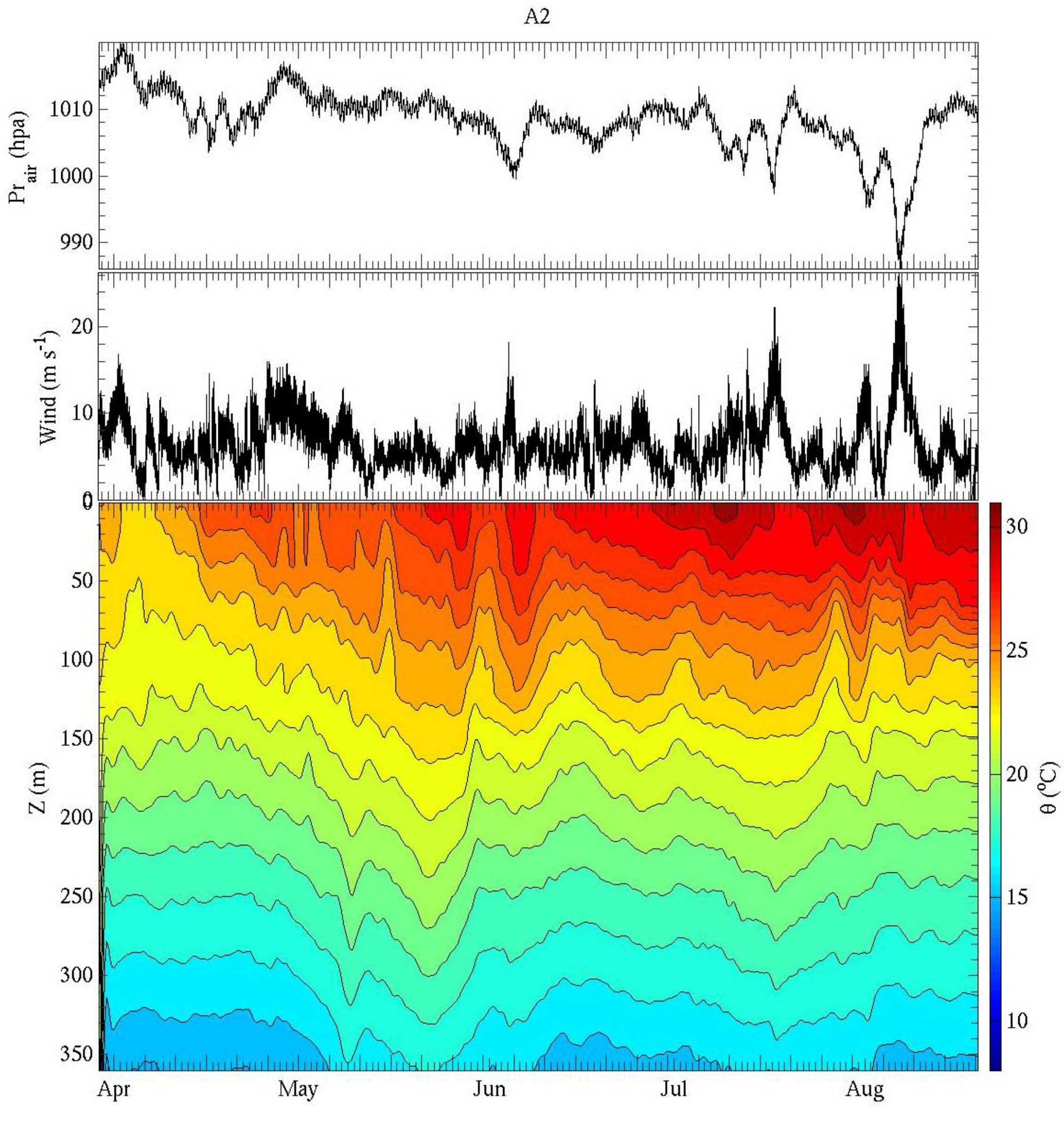

Figure 4. Air pressure, wind speed, and temperature observations at A2 mooring.

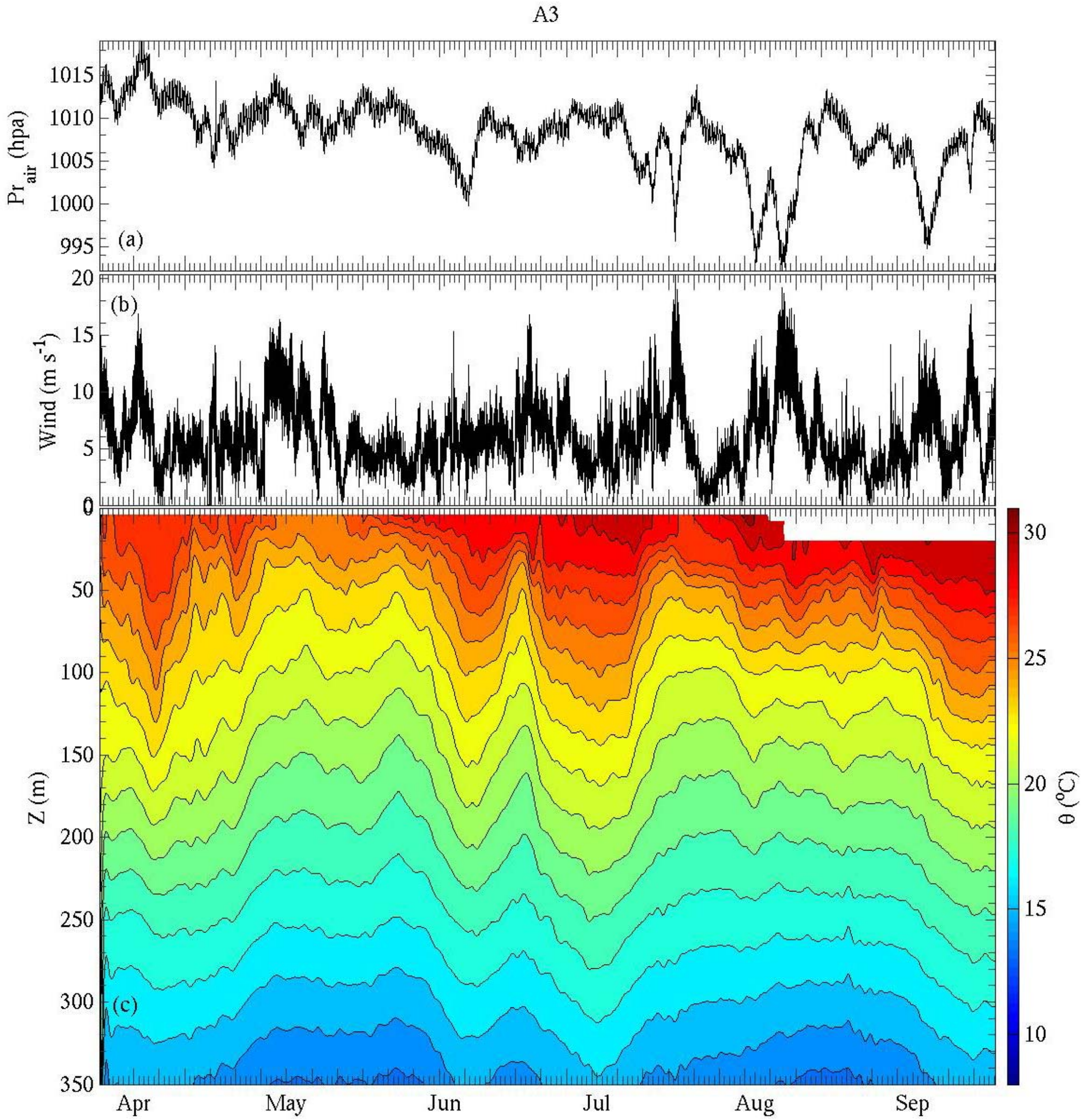

Figure 5. Air pressure, wind speed, and temperature observations at A3 mooring.

IMPACT/APPLICATION

The oceanic heat content could significantly modulate the strength of the passing tropical cyclones. Similarly, tropical cyclones could cause strong oceanic responses, e.g., forcing surface waves, inertial waves, and deepening the surface mixed layer, etc. To improve the skill of modeling oceanic responses to tropical cyclones and the prediction of tropical cyclones, we need to understand the small-scale processes responsible for the air–sea fluxes and interior mixing and the meso-scale oceanic processes that modulate the background oceanic heat content. The present field experiment will provide direct observations of oceanic responses forced by tropical cyclones and recovery after forcing, and aid understanding the dynamics of small-scale and meso-scale oceanic processes. These

observations will help improve the prediction skill of oceanic and atmospheric models in high wind regimes.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves (NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in 2005 and 2007 and a set of nearly one year of velocity-profile measurements taken in 2006–2007 from four bottom mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of NLIWI DRI will help improve our understanding of the dynamics of internal waves and their effects on the turbulence mixing in the upper ocean.

Study of Kuroshio Intrusion and Transport using Moorings, HPIES and EM-APEX Floats (N00014-08-1-0558) as a part of QPE DRI: The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs on the SECS , and 5) to provide our results to acoustic investigators to assess the uncertainty of acoustic predictions. Results of this DRI program will help understand oceanic physical processes on the southern East China Sea, e.g., the cold dome. Typhoons may modulate the Kuroshio, the Kuroshio intrusion, and other oceanic processes that result in cold pools on the continental shelf of the southern East China Sea.

HONORS/AWARDS/PRIZES

Gledden Sr. Visiting Fellowship at University of Western Australia (Sanford, October 2008).